Diode-Rectifying Circuits With Capacitance Filters

Discussion and author's closure of paper 41-105 by D. L. Waidelich, presented at the AIEE summer convention, Toronto, Ontario, Can., June 16–20, 1941, and published in AIEE TRANSACTIONS, 1941, pages 1161–7.

F. E. Terman (Stanford University, Stanford University, Calif.): Several years ago we had occasion to make a study somewhat analogous to that reported by Professor Waidelich. We included the effect of leakage reactance of the transformer, and found that this reduced the ratio of peak to average amplitude of the current pulse passing through the tube, and rounded off this pulse, but did not alter greatly the fraction of the cycle during which current flowed.

We also did some experimental work at the time using mercury-vapor rectifier tubes. We found difficulty under certain conditions, however, because the ignition voltage of the tubes that we used was normally greater than the voltage drop under operating conditions. That is to say, it took more voltage across the tube to start the conduction than it did to maintain the flow of current thereafter, and with some tubes the difference was considerable. This resulted in transients being set up which were especially troublesome during light loads, and which sometimes caused one of the tubes to fail to operate at all for brief moments as evidenced by flickering of that tube.

It would be interesting to know if Professor Waidelich has encountered any of these experimental difficulties, or if he was more fortunate in the characteristics of the rectifier tubes he was working with.

Reuben Lee (Westinghouse Electric and Manufacturing Company, Baltimore, Md.):

In AIEE paper 41-105 (May 1941) D. L. Waidelich has written a valuable paper on "Diode-Rectifying Circuits With Capacitance Filters." Previous analyses have dealt only with the case in which diode internal resistance is negligible. In the cases of appreciable diode resistance, calculation of performance required extremely involved equations, and many designers avoided them by resorting to experiment. Waidelich has now made both of these alternatives unnecessary by the plotting of his results in curves which reduce the designer's task to one of ease. At least, such is true of the relation between a-c and d-c voltage, and of the angle of conduction β-α.

In view of this accomplishment, it might seem regrettable that curves for maximum tube current, inverse peak voltage and ripple voltage are given only for the negligible diode resistance case. But while the paper does not so state, these latter relations can be found readily to close approximations for other values of diode resistance. For example, Waidelich shows in Figure 2 tube current of approximately quarter-sine wave form over the angle β-α. The average of this wave over 360 degrees is $0.636(\beta-\alpha)/360$ times the peak value.

$$\text{Whence } i_m=\frac{360I}{0.636(\beta-\alpha)}$$

How close this value is to actual peak current depends upon the ratio R_L/R_R. Series resistance R_R effectively rounds off the top of the tube current wave, making it more nearly a half-sine wave over β-α, the average value of which is the same as for a quarter-sine wave. For much practical work, the approximation is within five per cent of actual value.

The inverse peak voltage E_p is closely given by E_m+IR_L when the ripple voltage is small, as it is in many cases.

Ripple voltage, as found from Figures 15 and 16 or from equation 6 is true within a few per cent for all cases where $\omega CR_R \leqq 1$. This would be true, for example, if $\omega CR_L=$ 50 or less and $R_LR_R=50$ or more. Usually ripple-voltage accuracy is not so important as accuracy in d-c output voltage or peak-tube current. The values from Figures 15 and 16 or equation 6 are always higher than actual when diode resistance is not negligible.

D. L. Waidelich: Reuben Lee and F. E. Terman have both contributed interesting discussions on the subject of the paper.

Mr. Lee offers some helpful approximation methods for the calculation of maximum tube current, inverse peak voltage, and ripple voltage for certain values of the circuit parameters and tube resistance. The values of the above three quantities may be obtained from the angles β and α given in the paper, but the work is tedious, and for design use the results should be given in curve form. These quantities are given in the paper, however, for the case of zero tube drop while conducting, and a project to complete the work for any tube resistance is being carried on at the present time.

The effect of an ignition voltage greater than the conduction voltage for mercury vapor tubes as reported by Professor Terman was not observed during this study, but it may have been masked by the high a-c voltages employed at the input to the circuit. Oscillatory currents of relatively high frequency were observed, and transients such as these may have led to the troubles experienced by Professor Terman.

It is possible by the use of the results given in the paper to take account of the esistance of the transformer by including it with the tube resistance. The effect of leakage inductance must be considered in some other way, but the general effect of leakage reactance is to reduce the peak to average ratio of the tube current and to round off this current wave shape.